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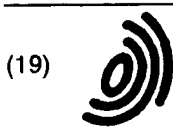
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(11) **EP 0 747 969 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
11.12.1996 Bulletin 1996/50

(51) Int Cl.⁶: **H01L 29/78, H01L 27/02**

(21) Application number: **96400695.1**

(22) Date of filing: **29.03.1996**

(84) Designated Contracting States:
DE FR GB IT SE

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(30) Priority: **07.06.1995 US 483692**

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(54) **Pilot transistor for quasivertical DMOS device**

(57) An isolated pilot transistor 100 for a QVDMOS device 10 has a gate and drain region in symmetry with the sources 20 of device 10 and an additional resistance

116 in the drain 118 to compensate for current spreading between the source 120 and the buried layer resistor 132.

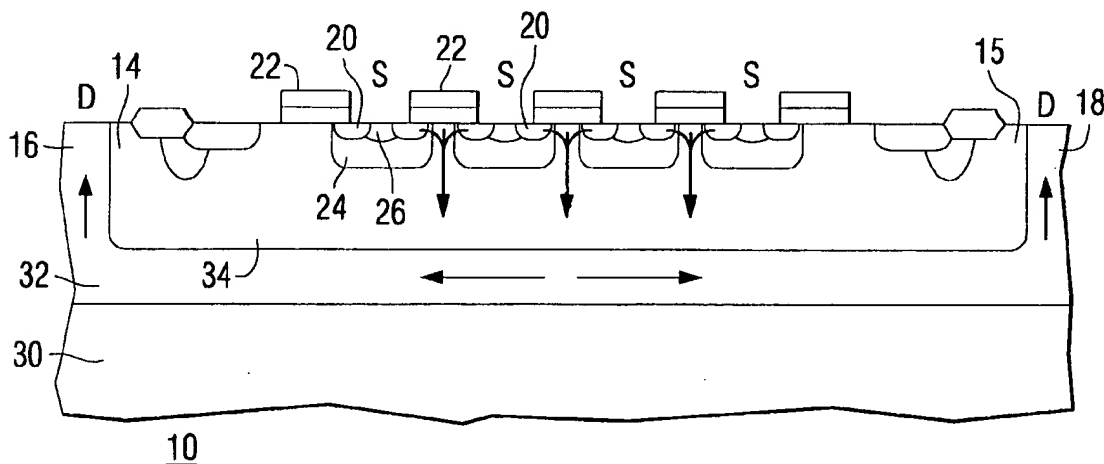


FIG. 2

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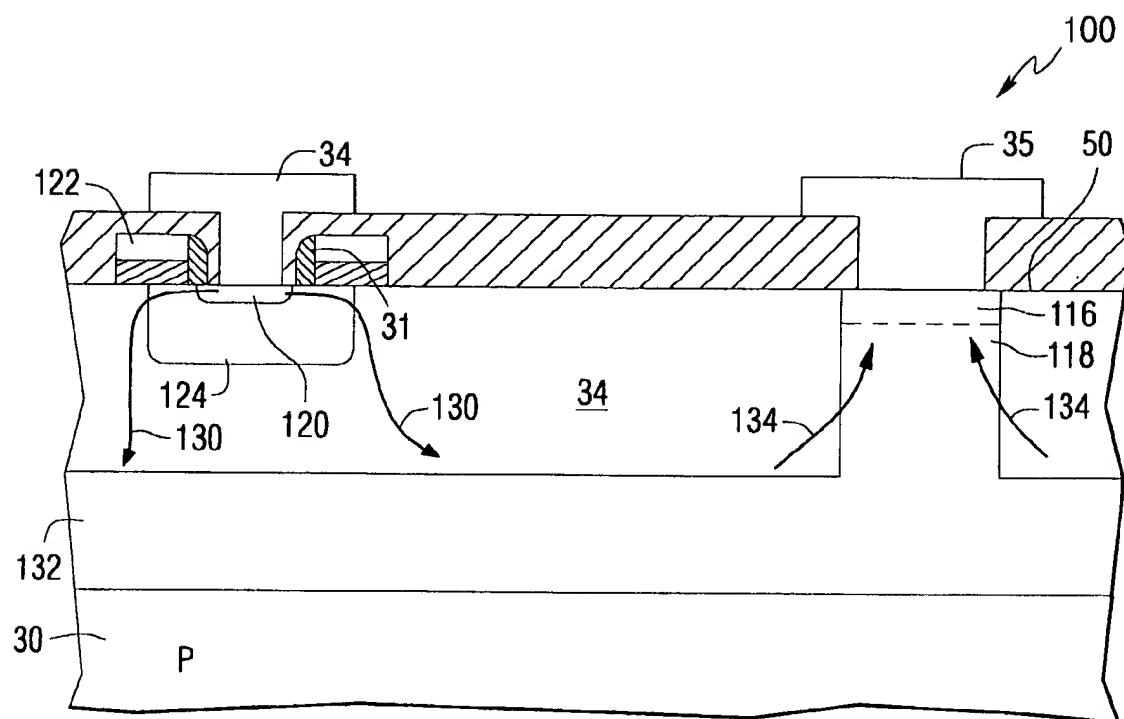


FIG. 4

Description

This invention relates to power devices, and in particular, to a pilot transistor for measuring power in a power device.

Integrated power devices have fully isolated power DMOS devices, typically in the form of an array. One particular type of fully isolated power DMOS device is a quasi-vertical DMOS (QVDMOS) device in the form of a power device with QVDMOS array. Such an array comprises a number of source cells each with a common gate disposed between a pair of lateral drain diffusions. Underlying the source cells is a buried layer that contacts the drain diffusions. Accordingly, current flows from the source cells into the buried layer and laterally toward the spaced-apart drain regions and then vertically up to the surface of the drain regions.

With power devices it is often desired to provide a pilot transistor that demonstrates substantially identical operating characteristics, albeit on a smaller scale, to the large power device array. So, if the array comprises 100 sources, then it is common to use a single transistor identical to the transistors in the array. The single transistor will be 1/100th the size of the array and will have operating characteristics including power characteristics proportional to the array.

One solution to the problem has been to use a source pilot that uses one of the embedded source cells. Such a solution is rather simple and depends upon selecting the optimum source cell among the array of sources in the DMOS device. However, it is often desirable to have pilot cell isolated from the source array so that the power in the source array can be effectively monitored by other low power devices such as CMOS control logic. In this way, a relatively low voltage and low power CMOS circuit can use a pilot transistor to monitor the high power of the QVDMOS device. So, the control logic and the pilot transistor can be fabricated on the same circuit yet remain separate. With such an arrangement, the control logic can monitor the power in the QVDMOS power device so that the device can be prevented from unsafe operation.

However, the traditional scaling approach for forming isolated pilot transistors is unsuccessful with power devices having a distributed nature such as an array of QVDMOS sources. By virtue of the distributed nature of the array, merely scaling a single pilot will not mimic the behavior of a large power device.

As such, there is a need for a pilot transistor that accurately matches the performance characteristics of the QVDMOS power device.

According to the present invention, an integrated circuit comprises a semiconductor substrate with a first conductivity and having a highly conductive QVDMOS buried layer of a second, opposite conductivity and having a QVDMOS buried layer resistance;

an epitaxial layer of said second conductivity and having an epitaxial resistance;

a quasi-vertical DMOS (QVDMOS) transistor having:

a DMOS body region of said first conductivity in said epitaxial layer for defining a QVDMOS channel of the QVDMOS transistor, said QVDMOS channel region having a QVDMOS channel resistance and a QVDMOS drift region in said epitaxial layer between said QVDMOS body region and said QVDMOS buried layer, said QVDMOS drift region having a QVDMOS drift resistance;

a QVDMOS source region of said second conductivity located in the DMOS body region and having a QVDMOS source resistance;

a QVDMOS gate electrically isolated from said epitaxial layer and at least partially covering a portion of the surface of the epitaxial layer between the DMOS body region and the QVDMOS source region;

a QVDMOS drain region of said second conductivity extending from the surface of the epitaxial layer to the buried layer and having a QVDMOS drain resistance;

said QVDMOS transistor having a resistance corresponding to the combined resistances of the QVDMOS source, body, drift, buried layer and drain regions;

a pilot transistor matched to the QVDMOS transistor, said pilot transistor having:

a pilot body region located in said epitaxial layer and substantially the same as said QVDMOS body region and defining pilot channel region and a pilot drift region;

a pilot source region located in said epitaxial layer and substantially the same as said QVDMOS source region;

a pilot gate electrically isolated from said epitaxial layer and at least partially covering a portion of the surface of the epitaxial layer between the pilot body region and the pilot source region;

a pilot buried layer of second conductivity and having a pilot buried layer resistance corresponding to the QVDMOS buried layer resistance;

a pilot drain region spaced from the pilot source region, having a second conductivity and having a pilot drain resistance corresponding to the drain resistance of the QVDMOS pilot.

Conveniently the QVDMOS power device has an array of source cells disposed between opposing drain termination regions at opposing drains. The pilot transistor comprises a source region having a source substantially identical to the sources in the source array of the QVDMOS device. The source array is surrounded by a gate termination region

having features similar to the portion of the gate surrounding the source cell in the power DMOS device. The source has a body or P-well region substantially identical to the P-well region of the QVDMOS device. Beneath the P-well region is a buried layer that is substantially identical in sheet resistance to the buried layer of the QVDMOS device. A surface drain region makes contact with the buried layer. The drain region may be identical in doping to the drain region of the QVDMOS device. In addition, it has been found necessary to add an additional resistance in series with the drain region in order to compensate for current spread. Current spread occurs in the pilot transistor because the single source cell does not have adjacent sources to confine the current from the source in its transit to the buried layer. As such, the pilot cell has effectively a lower resistance between the source and the buried layer than did the source cells of the power DMOS device. Such a reduction in resistance is compensated by adding an additional resistance in series with the pilot drain region or by modifying the resistance of the pilot drain region to account for both the resistance of the drain and the added compensating resistance. It is also compensated by using the symmetry of the source array to terminate the pilot gate and shape the pilot drain region.

The invention will now be described, by way of example, with reference to the accompanying drawings in which;

Figure 1 is a partial planar view of a power DMOS device having an array of source windows;
Figure 2 is a partial cross-sectional view of the array of Figure 1;
Figure 3 is a planar view of a pilot transistor for the DMOS device of Figure 1;
Figure 4 is a cross-sectional view of the pilot transistor;

Figure 1, shows a QVDMOS power device 10. A source region 12 is bordered on either side by identical drain termination regions 14, 15. Adjacent to drain termination regions 14, 15 are drain sinker regions, respectively, 16, 18. The sources are typically circular diffusions 20 that are bounded by a gate 22 with an hexagonal symmetry profile. In other words, the locus of points in a path around a source that is equidistant from the source and its neighbors defines a hexagonal path.

Figure 2 illustrates the QVDMOS device 10 is built on a semi-conductor substrate, typically a p-type silicon 30. In the substrate 30 there is a highly doped N+ buried layer 32. On top of buried layer 32 there is a lightly doped N-type epitaxial layer 34. The layer 34 is grown on the substrate 30 above the buried layer 32. Identical source regions 20 have annular regions of shallow N+ doping. The sources 20 are disposed in P-well DMOS bodies 34. In the middle of the diffusions 20 is a body tie 26. Gates 22 surround the sources. The source array 12 is spaced from opposite longitudinally running drains 16 and 18. Each of the drains 16 and 18 comprise heavily doped N-type regions that extend from the surface of the device to the buried layer 32. Drain termination regions 14, 15 respectively space the drains 16, 18 from the source array 12. In operation, when the DMOS device is on, current flows from the sources through a channel made in the DMOS body 24 through the epitaxial layer 34 and into the buried layer 32. Current in the buried layer 32 flows laterally towards the drains 16, 18. Accordingly, in its "on" condition, the QVDMOS device 10 includes a number of resistances such as the resistance of the sources 20, the MOS body resistance 24, the resistance of the epi layer 33, the resistance of the buried layer 34, and the resistance of the drains 16, 18.

In general, the QVDMOS device 10 has a specific "on" resistance. R_{spON} can be reasonably modeled over pertinent conditions by the following relationship :

$$R_{spON} = R_{spD} \left(\frac{W_v \cdot D}{2} \cdot T \right) \left(R_{shBL} \cdot T \cdot \sqrt{(R_{spMOS} \cdot R_{spEPI}) \cdot R_{shBL}} \cdot \cosh \left(\sqrt{\frac{R_{shBL}}{(R_{spMOS} \cdot R_{spEPI})}} \cdot \frac{W_v}{2} \right) \right)$$

(1)

where

R_{spD} = effective drain sinker specific resistance (ohm*cm²)
 R_{shBL} = N+ buried layer sheet resistance (ohm/square)
 R_{spMOS} = effective MOS specific resistance (ohm*cm²)
 R_{spEPI} = effective epi drift region specific resistance (ohm*cm²)

The dimensions W, V, T, and L are as in Figure 1. Each R component above exhibits its own unique bias, temperature, and process variations. R_{spMOS} (region 24) is the most variable in the range of pertinent operation for power switches; it may vary by as much as 5:1 with changes in gate bias being the most important source of variation. R_{spEPI}

layer 34) is also important in its variation, especially with process (i.e. epi thickness and doping) and temperature. Both R_{shBL} (layer 32) and R_{spD} (drains 16, 18) are heavily doped silicon and have small to negligible variation with temperature and bias. R_{spD} is typically a very small portion of the total power device resistance. R_{shBL} , on the other hand, is an important element accounting for about 35% of the total power device resistance, so process variations in R_{shBL} are important to accurate pilot devices. The hyperbolic cotangent term accounts for the distributed nature of the vertical DMOS by way of a distributed resistance line model. Under normal operating conditions for an optimized power device, the hyperbolic cotangent can be linearized as below.

$$R_{pON} = R_{pD} \cdot \left(\frac{W_v \cdot D}{2} \cdot T \right) (R_{shBL} \cdot T + \frac{2}{W_v} (R_{pMOS} + R_{pEPI}) + \frac{W_v}{3} R_{shBL}) \quad (2)$$

The smallest pilot device would be based on a single source window. As such it would be well described by a lumped element circuit model with

$$R_{pON} = R_{pD} + R_{pBL} + R_{pMOS} + R_{pEPIs} + R_{pEPId} \quad (3)$$

The resistor components are specific to the pilot geometry with the same physical origins as in the full device expression indicated by the subscripts. Figure 3 shows a general layout of a pilot with these elements. Details of the bias and temperature dependence may still depend on the device geometry, especially for R_{pMOS} and R_{pEPI} . The key to matching pilot and power device performance is to have the relative ratios of the four primary resistor elements the same in both devices. Then any variations in any term, to first order, will have the same impact on both the power and pilot devices.

The R_{pMOS} element is best matched by forming a single source window and terminating the gate such that the symmetry lines of the QVDMOS source array are simulated in the pilot. This is easily done by ending the gate electrode 122, with appropriate termination, at the symmetry lines. Such a construction duplicates most of the important geometries that determine this component's behavior at low drain bias. At high drain bias the terminating junction will contribute a depletion spread not present in the power device. However, for most piloting of power switches, only the low drain bias conditions are important since the switch is not intended to sustain high conductance and high voltage simultaneously.

The R_{pEPIs} term also benefits from the single source window construction. However, another geometric discrepancy between pilot and power devices becomes apparent. In the power device 10, symmetry confines the current from crossing the source array symmetry lines (except at edges of the vertical section). In other words, the current travels an almost vertical path to the buried layer 32. In the pilot, the absence of surrounding sources allows the current to spread beyond the source array symmetry lines and it proceeds from the surface to the N+ buried layer. See arrows 130 in Figure 4. This current spreading reduces R_{pEPIs} below the level required by the component ratios in the power device. That is why a R_{pEPId} term was added to the pilot expression. This term is added by providing another section of vertical current flow through the epi, sized accordingly to add the extra epi resistance needed raise the total R_{pEPI} component to the needed value. This path can replace the drain sinker 118 (if that term is small enough) or it can be just an extra element in the pilot design. The final term, R_{pBL} , is present in the power device due to the distributed drain collection term (with the $W_v/3$ factor) and the drain termination term (with the T factor). Since neither mechanism is inherent in the pilot, care must be taken to include an appropriate N+ buried layer resistor 132 to provide this important component. This is clearly shown in Figures 3 and 4.

Turning to Figures 4 and 5, there is shown a pilot transistor 100 that satisfactorily tracks the QVDMOS device 10. The source 120 is a shallow N+ source that is simultaneously formed with the sources 20 of the QVDMOS device 10 on an area of the substrate 30 spaced from the QVDMOS device 10. The source 120 is surrounded by an approximate hexagonal gate 122 in order to maintain the symmetry of the gate source relationship as found between sources 20 and gates 22 in the QVDMOS device 10. Likewise, the drain region 118 is also patterned to have an hexagonal shape. The symmetry between the approximate hexagonal shape of the drain region 118 and the gate 122 allows the drain region 118 to concentrate the current flowing from the buried layer 32 as will be explained hereinafter.

The source region 120 is formed in a lightly P doped DMOS body 124 that is simultaneously fabricated with the DMOS body 124 of the source array cells 20. The DMOS body 124 is formed in the same epitaxial layer 34 and has the same light N-type doping as the epitaxial layer 34 that holds the source bodies 24. The buried layer resistor 132 is the same buried layer found in the DMOS device 32. An optional region 116 is found in the drain diffusion 118. The drain diffusion 118 can be fabricated to have a suitable drain resistance to compensate for the current spread from the

source. As shown by arrows 130, current from the source tends to spread out laterally in its downward passage towards the buried layer 32. As a result, the effective resistance of the epitaxial region 34 is reduced in the pilot transistor 130. This reduction in effective epitaxial resistance would render the pilot transistor inconsistent with the operation and the "on" resistance of the QVDMOS device 10. So, to compensate for this spread in current, the shallow P+ drain region 118 is formed in an hexagonal shape in order to concentrate current from the buried layer 132 at the surface 50. As such, the symmetrical arrangement tends to provide an "inverse lampshade" for the current from the buried layer resistor 132. So, while the current 130 spreads out from the source and reduces resistance, the hexagonal shape of the drain 118 tends to concentrate the current along lines 134 and increases resistance. In an alternative embodiment, a further resistance could be added in series with the drain 118 such further resistance would increase the total on resistance of the pilot device 100 and make up for any remaining differences in the reduction of resistance due to the lateral spreading of current from the source 120.

Advantageously, the invention provides a suitable pilot transistor 100 that mimics the operation of the DMOS device 10. The isolated pilot transistor 100 employs symmetry in the formation of the gate and the drain and thereby compensates for the lack of symmetry due to the single source isolated from the array. In order to finally compensate for reduced resistance due to current spreading from the source, an epitaxial resistance is added to the drain region and thereby compensates for reduced drift region resistance.

More specifically, the approximate hexagonal shape of the gate 122 and drain 118 is not critical. Other symmetrical shapes may be used, including, by way of example a circle or an octagon.

An isolated pilot transistor 100 for a QVDMOS device 10 has a gate and drain region in symmetry with the sources 20 of device 10 and an additional resistance 116 in the drain 118 to compensate for current spreading between the source 120 and the buried layer resistor 132.

Claims

1. An integrated circuit comprising:

a semiconductor substrate with a first conductivity and having a highly conductive QVDMOS buried layer of a second, opposite conductivity and having a QVDMOS buried layer resistance;
 an epitaxial layer of said second conductivity and having an epitaxial resistance;
 a quasi-vertical DMOS (QVDMOS) transistor having:
 a DMOS body region of said first conductivity in said epitaxial layer for defining a QVDMOS channel of the QVDMOS transistor, said QVDMOS channel region having a QVDMOS channel resistance and a QVDMOS drift region in said epitaxial layer between said QVDMOS body region and said QVDMOS buried layer, said QVDMOS drift region having a QVDMOS drift resistance;
 a QVDMOS source region of said second conductivity located in the DMOS body region and having a QVDMOS source resistance;
 a QVDMOS gate electrically isolated from said epitaxial layer and at least partially covering a portion of the surface of the epitaxial layer between the DMOS body region and the QVDMOS source region;
 a QVDMOS drain region of said second conductivity extending from the surface of the epitaxial layer to the buried layer and having a QVDMOS drain resistance;
 said QVDMOS transistor having a resistance corresponding to the combined resistances of the QVDMOS source, body, drift, buried layer and drain regions;
 a pilot transistor matched to the QVDMOS transistor, said pilot transistor having:
 a pilot body region located in said epitaxial layer and substantially the same as said QVDMOS body region and defining pilot channel region and a pilot drift region;
 a pilot source region located in said epitaxial layer and substantially the same as said QVDMOS source region;
 a pilot gate electrically isolated from said epitaxial layer and at least partially covering a portion of the surface of the epitaxial layer between the pilot body region and the pilot source region;
 a pilot buried layer of second conductivity and having a pilot buried layer resistance corresponding to the QVDMOS buried layer resistance;
 a pilot drain region spaced from the pilot source region, having a second conductivity and having a pilot drain resistance corresponding to the drain resistance of the QVDMOS pilot.

2. An integrated circuit as claimed in claim 1 wherein the QVDMOS gate comprises an array with a plurality of source cells, a continuous gate having openings and each opening having a first shape and enclosing a source cell thereby defining a symmetry for said array, said pilot gate having a first shape corresponding to the symmetry of the QVDMOS gate surrounding a QVDMOS source cell, said pilot drain region formed in said substrate and having a surface

shape corresponding to the first shape whereby the symmetry of the QVDMOS source array is repeated in the pilot transistor.

3. An integrated circuit as claimed in claim 2 wherein the pilot drain has a resistance greater than the resistance of the QVDMOS drain to compensate for reduced drift resistance in the epitaxial layer of the pilot transistor.

4. An integrated circuit as claimed in any one of claims 1 to 3 including the QVDMOS power device having a symmetrical source array with each source disposed in a body region, a buried layer beneath the source array and a drain region in contact with the buried layer, comprising the pilot transistor, electrically isolated from the QVDMOS power device and having a source disposed in a body region substantially the same as the source and body region of the QVDMOS power device;

said pilot transistor source disposed over the same buried layer as the QVDMOS buried layer;

a pilot drain contacting said buried layer; and

a compensating resistance located between the buried layer and the drain, said compensating resistance having a magnitude sufficient to raise the resistance of the pilot transistor to the resistance of the QVDMOS transistor.

5. An integrated circuit as claimed in claim 4 wherein the pilot transistor further comprises a gate region having an annular shape with its outer periphery corresponding to the symmetry of the QVDMOS source cell and the pilot drain having a shape at the surface of the substrate with a shape corresponding to the outer periphery of the pilot gate.

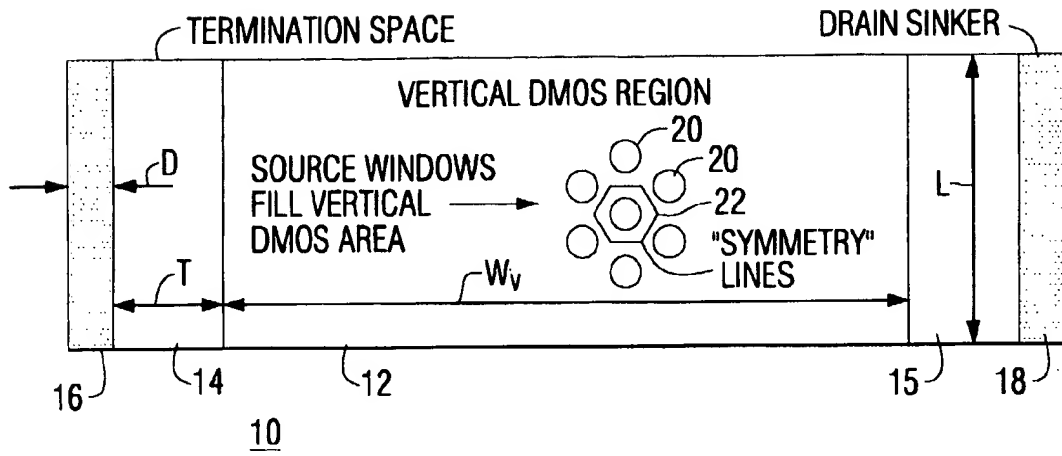


FIG. 1

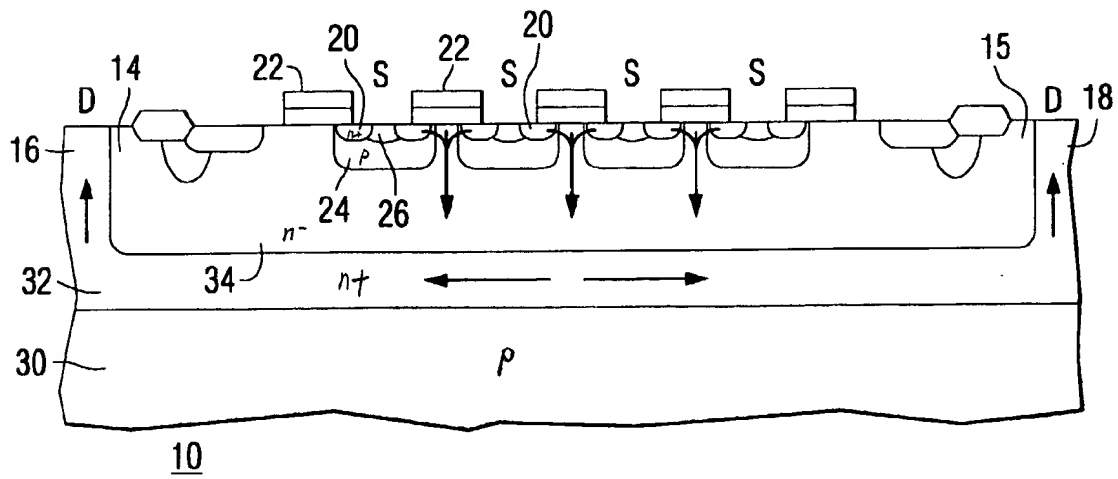


FIG. 2

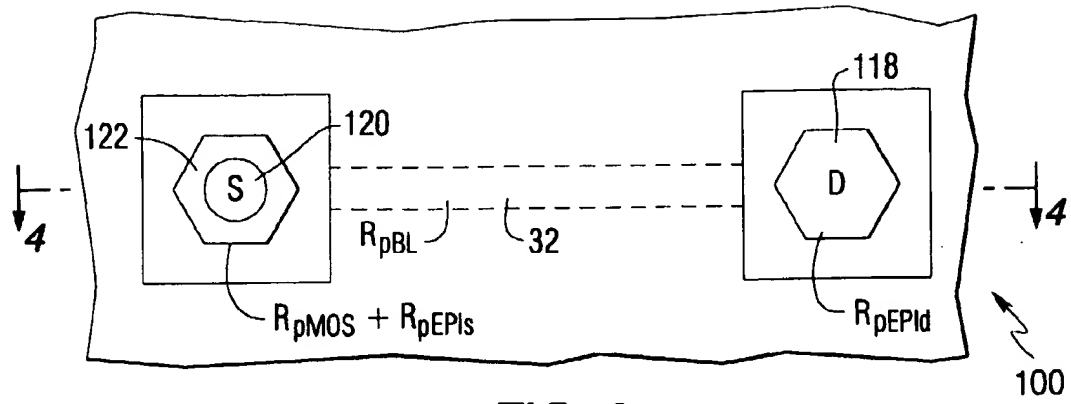


FIG. 3

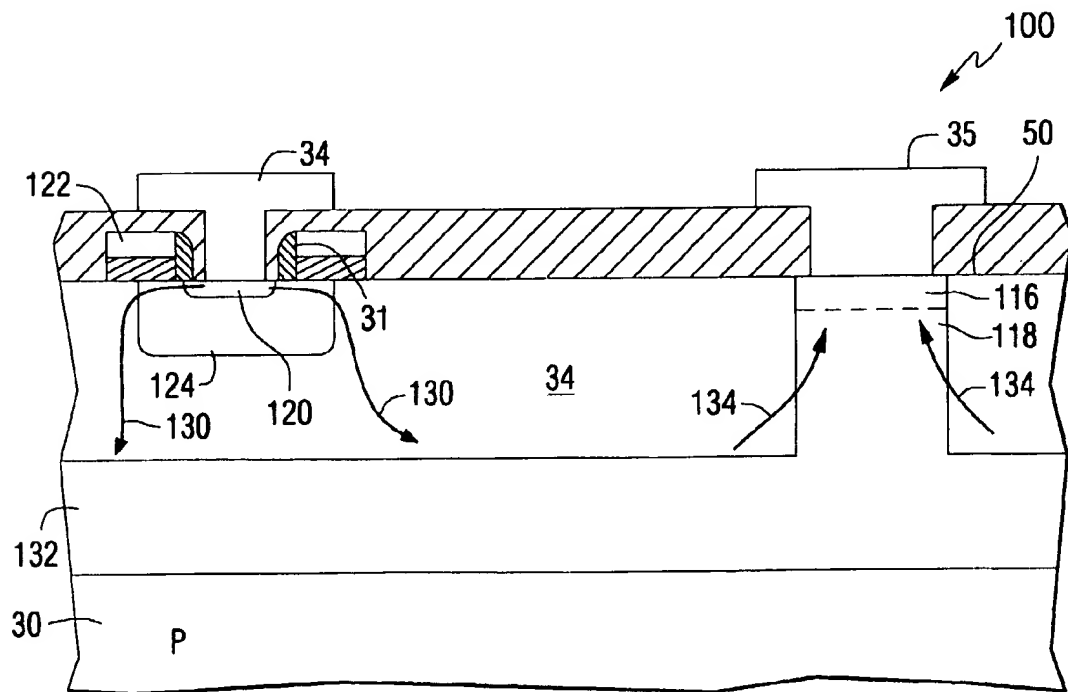


FIG. 4



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Application Number
EP 96 40 0695

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.CL.6)
A	PATENT ABSTRACTS OF JAPAN vol. 018, no. 035 (E-1494), 19 January 1994 & JP-A-05 267675 (FUJI ELECTRIC CO LTD), 15 October 1993, * abstract *	1-5	H01L29/78 H01L27/02
A	EP-A-0 557 253 (SGS THOMSON MICROELECTRONICS) 25 August 1993 * figure 2 *	1-5	
A	DE-A-42 09 148 (FUJI ELECTRIC CO LTD) 15 October 1992 * abstract; figures *	1-5	
A	US-A-5 256 893 (YASUOKA HIDEKI) 26 October 1993 * figures *	1-5	
			TECHNICAL FIELDS SEARCHED (Int.CL.6)
			H01L
The present search report has been drawn up for all claims			
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